ECHOCARDIOGRAPHY: STATE OF THE ART

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ECHOCARDIOGRAPHY has become a routine technique for imaging the heart and many busy laboratories perform 15 to 20 patient studies daily. Because echocardiography is safe, rapid and reproducible, it has gained an important position in the ever increasing armamentarium for cardiac evaluation. More recently, cardiothoracic surgeons and anesthesiologists have begun to utilize echocardiography intraoperatively to shorten their diagnostic and therapeutic response time.

Echocardiography is based upon principles of sonar first developed for military and commercial purposes. The radar technique that ships used to detect underwater mines, submarines and overhead aircraft is based upon the emission of sound waves. If the velocity of the emitted sound wave is known and the time for the sound wave to reach an object and return to the emitting source is calculated, the exact distance of that particular object from the emitting source can be determined. In echocardiography, a transducer emitting sound waves toward the heart is put directly on the chest wall in the left parasternal position. The time required for the sound beam to reflect off an intracardiac surface and return to the transducer can precisely localize that structure. Additionally, as in routine radiography, different surfaces reflect sound waves to different degrees: calcium on valves or in scar regions are extremely echodense, while blood allows complete transmission of sound waves and is echo lucent.

Echocardiography began with a probe emitting a single narrow sound wave beam (M-mode), similar to putting a thin ice pick through the heart. Only a very limited section of the heart could be seen at any single point in time. Presently, echocardiography routinely combines both M-mode and two-

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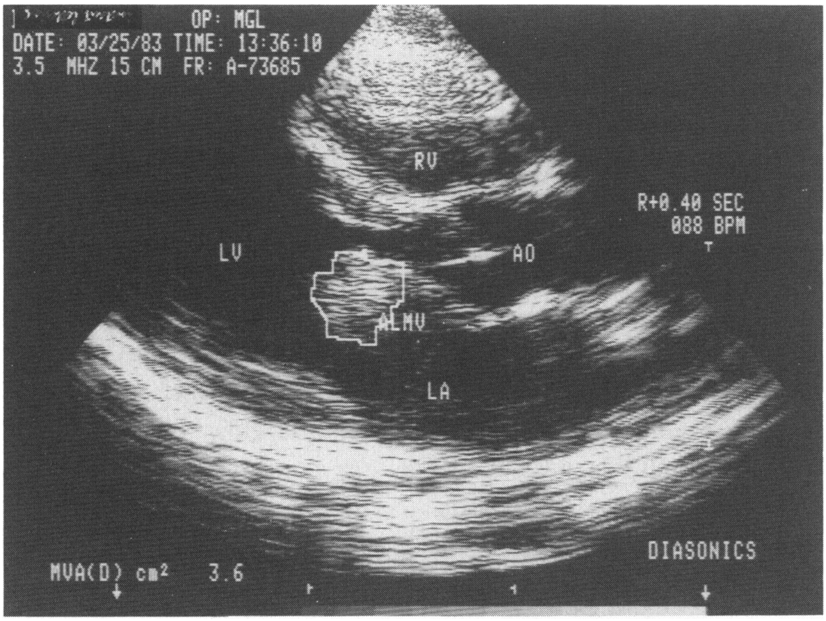

Fig. 1. Mitral valve vegetation. In this parasternal long axis view, a large vegetation is seen on the anterior leaflet of the mitral valve (ALMV). A vegetation is seen as a fluffy, white density attached to the valve.

dimensional echocardiography. Two-dimensional (2-D) echocardiography is the use of multiple sound wave beams simultaneously to look at larger sections (60-90° sector) of the heart in motion and in real-time. Additionally, a single beam can be isolated from the multiple 2-D beams to give an M-mode echocardiogram.

The single beam M-mode echocardiogram provides a hard copy tracing from which measurements are easily made. An M-mode echocardiogram allows immediate hard copy quantification of wall thickness and cavity dimension which is easier to analyze than routine 2-D echocardiograms. However, M-mode echoes are limited in that only one narrow section of the heart is seen at one time, whereas 2-D echo visualizes a larger segment. But, when derived from a 2-D echo, an M-mode can be obtained quickly and accurately. Therefore, a combined M-mode and 2-D study provides both a qualitative and quantitative evaluation of the heart.

The 2-D sound wave beam is analogous to a thin fan which can slice the heart in several different planes. Along the long axis the heart is sliced from the base to the apex (one end of a salami to the other) (Figure 1). If the sound wave beam is rotated ninety degrees, the short axis view is imaged (Figure 2). This view cuts the heart into ''salami slices'' from base to apex. This is an important view used for evaluation of ventricular function. When the transducer is directed throught the apex of the heart, all four chambers of the heart can be seen (Figure 3).

Mitral Valve

A single M-mode beam at the mitral valve level demonstrates the double M pattern corresponding to rapid atrial emptying, diastasis and the atrial kick. The two-dimensional echocardiogram images the mitral valve in several planes. Importantly, the short axis view can image the orifice of the valve (Figure 4). In mitral stenosis the valve area is markedly diminished, commissures are fused and leaflets thickened. The M-mode echocardiogram would appear to demonstrate a thickened valve with decreased mobility (decreased E-F slope) (Figure 5). Quantification of the degree of mitral stenosis is difficult on the basis of an M-mode alone, but the exact valve area can be planimetered from the 2-dimensional short axis view, providing an accurate orifice dimension. In addition, from several 2-D views a large left atrium can be examined for thrombi. One of the commonest referring diagnoses to an echocardiography lab is mitral valve prolapse, which can be either holosystolic or late systolic hammocking of the mitral valve into the left atrium (Figures 6, 7).

Aortic Valve

The normal aortic valve has three cusps: the right cusp from which the right coronary takes off, the left cusp with the left coronary artery and the noncoronary cusp. Ordinarily, the M-mode beam images the aortic valve as a box, made up of only two of its cusps, the right and noncoronary cusps; the left coronary cusp is not routinely imaged. By 2-D echocardiography, all three cusps and the relative size of valve orifice are seen (Figure 5). However, even by 2-D echocardiography, the severity of aortic stenosis can only be estimated by the maximum aortic cusp excursion.

Left Ventricle

A left ventricular M-mode echocardiogram can assess the degree of thickening of the septal and posterior walls and the cavity dimensions in systole

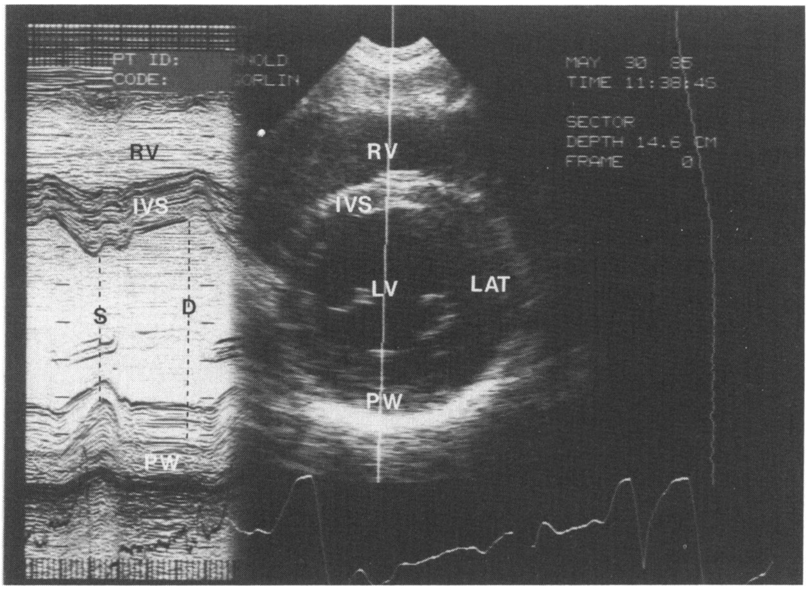

Fig. 2. Short access view—papillary muscle level. On the right is seen a short axis view at the level of the chordae and papillary muscle. An entire circumferential cross-section of the ventricle is seen in this view: the interventricular septum (IVS), the lateral wall (LAT), and the posterior wall (PW). On the left is the M-mode echocardiogram taken from the M-mode beam seen on the two-dimensional echocardiographic cut. Ventricular filling and contraction can be seen, represented as the smaller cavity during systole (S) and the larger cavity during diastole (D).

and diastole. By viewing several different beats over time, overall contractility, the effect of ischemia and myopathic abnormalities can be seen. Unfortunately, because the M-mode is only a single beam, only a thin part of the anterior septum and posterior wall are seen. However, by 2-D echocardiography the entire circumference of the ventricle at different levels can be imaged (Figure 2). Contraction abnormalities not visualized by M-mode are easily identified by 2-D.

Two-dimensional echocardiogram is considered the best noninvasive technique to determine the presence or absence of ventricular and atrial thrombi (Figure 3). However, left atrial thrombi may be located in the atrial appendage which cannot be adequately imaged by M-mode nor 2-D echocardiography.

Hypertrophic Cardiomyopathy

Normally in the short axis view of the heart, ventricular wall thickness and contractility are fairly symmetrical. In hypertrophic cardiomyopathy,

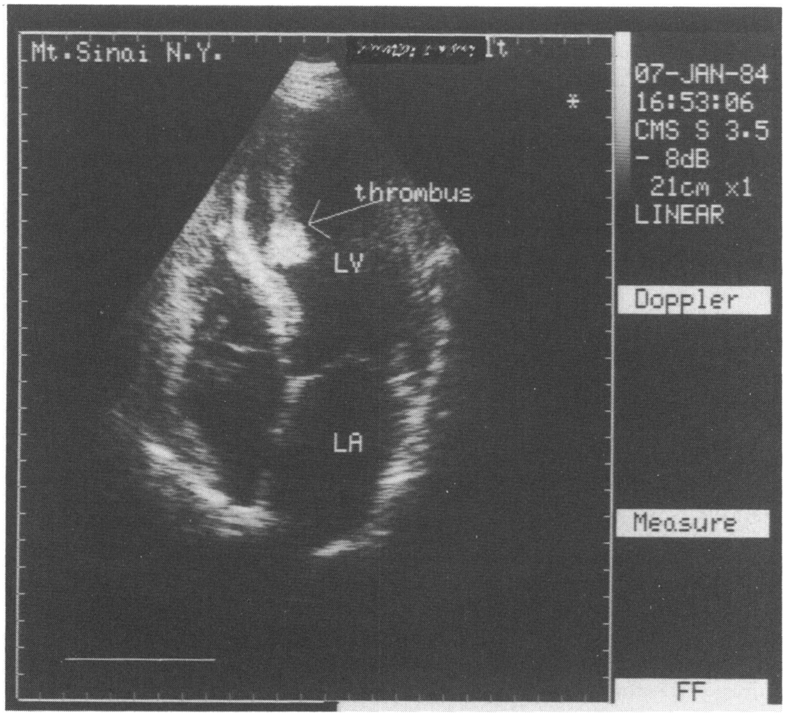

Fig. 3. Left ventricular thrombus. In this apical four-chamber view, a large left ventricular thrombus is seen along an infarcted interventricular septum (arrow). LA=left, atrium, LV=left ventricle).

or idiopathic hypertrophic subaortic stenosis, the interventricular septum is markedly thickened (Figure 8). Hypertrophic cardiomyopathy is an important disease because it can masquerade as myocardial infarction, or congestive cardiomyopathy, presenting with pulmonary edema, chest pain, serious arrhythmias or sudden death. Previously, the only technique to evaluate and diagnose this disorder was invasive cardiac catheterization. Recently, M-mode and two-dimensional echocardiography have allowed accurate noninvasive evaluation. In hypertrophic cardiomyopathy a dynamic outflow obstruction related to the thickened interventricular septum is creating a Venturi effect which draws the mitral valve up in a position against the septum to generate obstruction to aortic outflow. During systole, the hypercontractile ventricle virtually obliterates its cavity. The treatment for this problem is negative inotropic agents, beta-blockers or calcium antagonist or, if necessary, ventricular myomectomy. Two-dimensional echocardiography can evaluate the entire septum and the mitral valve motion both for initial diagnosis and subsequent response to therapy.

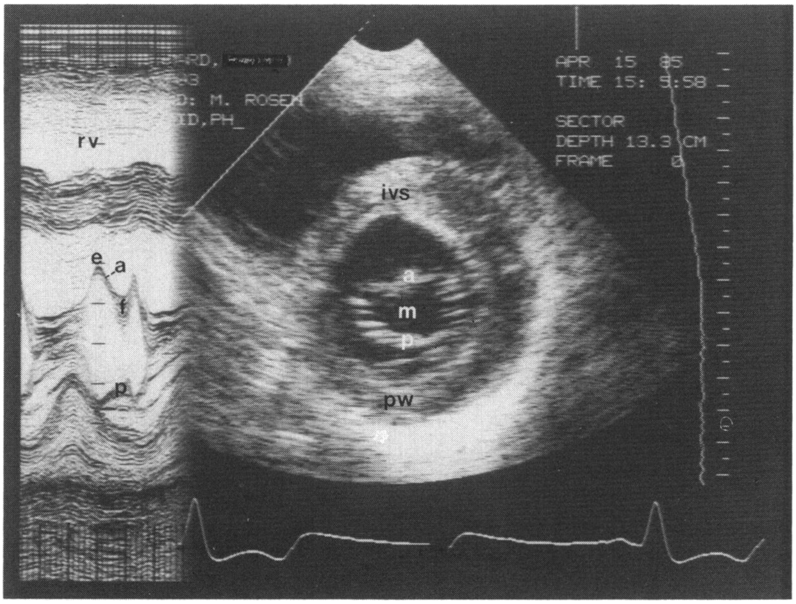

Fig. 4. Short access view at the mitral valve level. On the right the anterior (A) and the posterior (P) leaflets of the mitral valve are seen. In the left figure the mitral valve is seen on the M-mode. The E-F slope represents the rapid filling phase of the left ventricle.

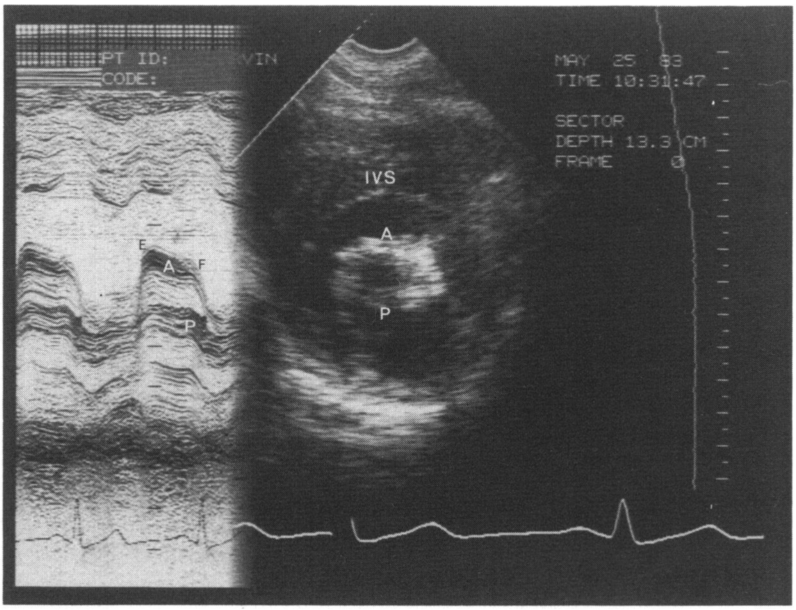

Fig. 5. Mitral senosis. The right figure demonstrates a narrowed orifice of a calcified mitral valve. The orifice is diminished. On the left, the M-mode echocardiogram shows the thickened anterior and posterior leaflets of the mitral valve and a decreased E-F slope due to the obstruction to inflow of blood into the left ventricle due to the mitral stenosis.

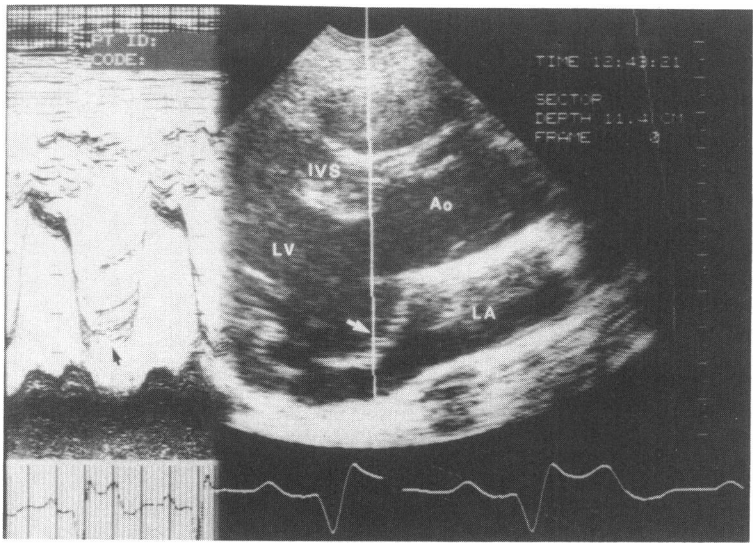

Fig. 6. Mitral valve prolapse. The left side points to holo-systolic hammocking of the mitral valve (arrow) on the M-mode echocardiogram taken from the two-dimensional echo long axis view. The 2-D echo demonstrates hammocking of the anterior leaflet of the mitral valve (arrow).

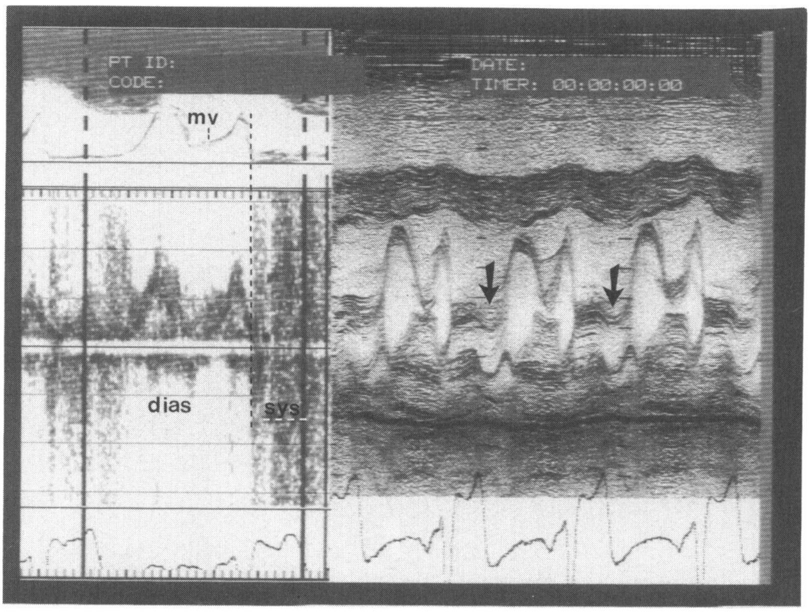

Fig. 7. Mitral valve prolapse. On the right side, the mitral valve is seen to prolapse in late systole (arrows). However, the Doppler echocardiogram on the left side shows there is systolic turbulence immediately following closure of the mitral valve consistent with holosystolic mitral regurgitation.

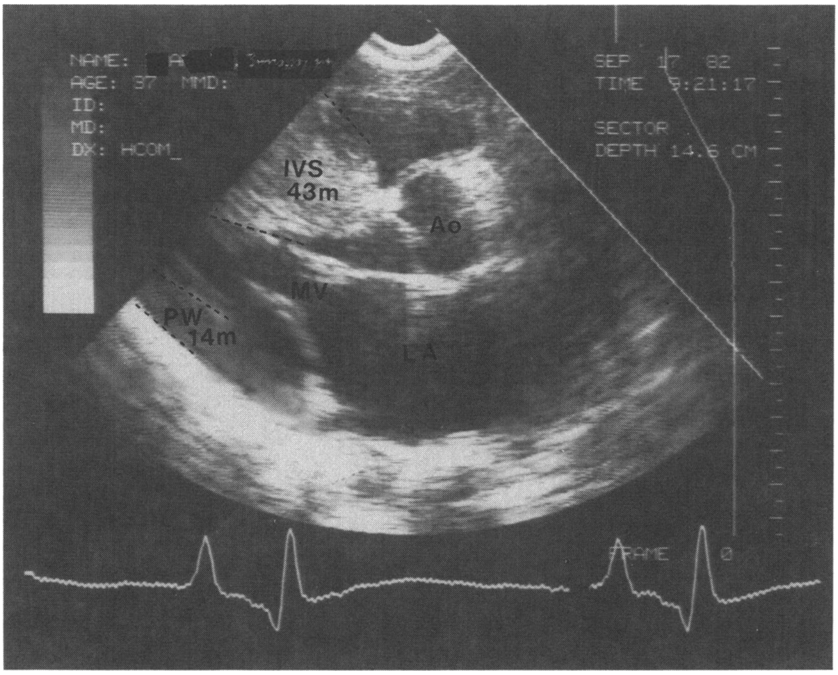

Fig. 8. Hypertrophic cardiomyopathy or idiopathic hypertrophic subaortic stenosis (IHSS). In this parasternal long axis view is shown a very thick interventricular septum (IVS) measuring 43 mm (Normal ≤ 11 mm). Also, an abnormal speckling pattern of the myocardium, typical of the myocardial disarray is evident.

Pericardial Effusions

Echocardiography is the most rapid and accurate method to diagnose and quantify pericardial effusions secondary to malignancies, renal failure, viral infection or idiopathic causes (Figure 9). With increasing accumulation of pericardial fluid, a typical rocking of the heart is seen with expiratory collapse of the right atrium and right ventricle. These signs are important correlates of pericardial tamponade. The 2-D echocardiogram is invaluable in locating the loculated effusions commonly seen postoperatively.

Endocarditis

One of the important advances of echocardiography has been in the evaluation of patients who have endocarditis. It is invaluable in confirming which valve is infected and related complications, such as abscess formation, leaflet destruction and chamber dilatation (Figure 1). The echocardiogram is es-

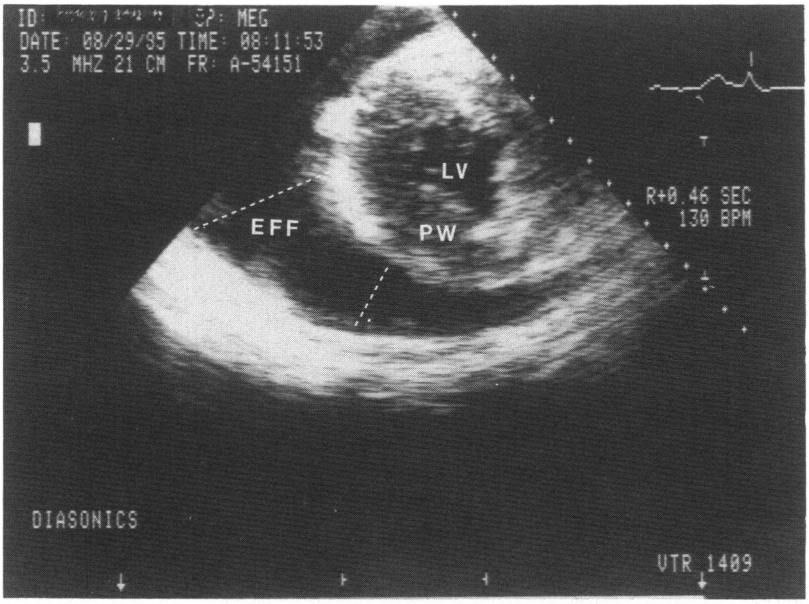

Fig. 9. A pericardial effusion. This two-dimensional echocardiographic view demonstrates a very large pericardial effusion (EFF) in which the left ventricle is seen to rock, consistent with the clinical diagnosis of pericardial tamponade. (PW=posterior wall)

pecially valuable in the work-up of fevers of unknown origin and drug addicts, who frequently have multiple potential sources of fevers. The presence, of any sized vegetation confirmed by echocardiography puts the patient in an overall higher risk group. Importantly, a recent study in our lab suggested that large vegetations, especially on the aortic valve, appears to have grave prognostic implications for the development of major complications during the patient's hospital course.

Contrast Echocardiography

An additional technique in echocardiography is contrast echocardiography. Injection of 10 mls of D_5W or saline through a peripheral vein creates spontaneous microbubbles, probably related to microsequestration of air along the tubing system. When a bolus of fluid is injected into a peripheral vein, contrast quickly fills sequentially the right atrium and right ventricle, leaving by the pulmonary artery and then finally dissipating in the lungs. However, in the presence of ventricular or atrial communications, contrast transverses across the defect into the left side of the heart. Contrast echocardiography has been utilized intraoperatively in our laboratory accurately to assess the presence and severity of mitral and tricuspid regurgitation before and immediately following valve surgery.

Coronary Anatomy

One of the important new applications of echocardiography is in the evaluation of coronary artery anatomy. Occasionally, the origin of the left main, left circumflex, the left anterior descending and the right coronary artery can be imaged. Significant stenoses of the proximal coronaries can be seen. In patients with Kawasaki's disease or mucocutaneous lymph node syndrome, coronary artery aneurysms can be detected. High frequency transducers are now being developed to image the coronary arteries in the open chest. Both the coronary lumen and the plaque partially occluding the vessel could be localized.

Intraoperative Echocardiography

Present equipment is fairly portable, and can be taken into the operating room for imaging on the chest or directly on the exposed heart. Using echocardiography in the operating room, it is possible directly to visualize myocardial dysfunction and infarction earlier than can be detected by the electrocardiogram. This is invaluable in differentiating ventricular dysfunction from hypovolemia in hypotensive patients with difficulty coming off bypass. A patient with a small ventricular cavity and excellent contractility would benefit from volume expansion, while prompt institution of inotropic support would be critical for a patient with severe myocardial dysfunction. Recently, contrast echocardiography has been used to evaluate valvular repair and replacement procedures intraoperatively to detect significant regurgitation which can be repaired before the patient leaves the operating suite.

Transesophageal Echocardiography

Another new intraoperative monitoring technique is transesophageal echocardiography in which a small, wafer-thin ultrasound transducer is mounted on a gastroscope and positioned in the esophagus behind the heart. Anesthesiologists use transesophageal echocardiography to monitor ventricular function and volumes intraoperatively. Wall motion abnormalities easily detectable by echocardiography precede even the electrocardiogram and pulmonary artery catheter in detecting ischemia.

Transesophageal echocardiography may be particularly invaluable in cardiac patients undergoing noncardiac surgery in the diagnosis and prompt therapy of intraoperative myocardial ischemia.

Exercise Echocardiography

Echocardiographic imaging of myocardial contractility during or immediately following exercise can reveal ventricular dysfunction undetected in the basal state. During supine bicycle or immediately after routine upright treadmill exercise, wall motion abnormalities can be localized by echocardiography. Technical difficulties may arise in imaging due to large respiratory excursions of the chest wall with exercise-induced hyperventilation. However, digitization of the echo images and viewing several cine loops may enhance the sensitivity of the technique. Results of studies comparing exercise echo data to other stress techniques have been very favorable.

Tissue Characterization

Tissue characterization is one of the more sophisticated applications of echocardiography and has exciting potential. Specific intensities of echoes from varying tissue densities can potentially be identified depending on several variables. This is an exciting new area for very early detection of myocardial infarction. Potentially, early abnormalities of tissue texture related to deposition of calcium from cellular damage or potential edema related to inflammation, infiltrative disease, amyloid, deposition and other causes may be identified by this method.

Doppler Echocardiography

Doppler flow studies are now used in tandem with the echocardiogram to determine cardiac valvular and flow pattern abnormalities. The Doppler effect is a shift in the observed frequency of a sound wave due to the motion of the target object. Very simply stated, if a moving column of blood is being imaged by an emitted sound wave beam which has a certain frequency, that frequency is shifted to a different frequency depending on the velocity of the blood movement. The faster the blood moves, the greater the frequency shift. This can be detected by two-dimensional echocardiogram machines equipped with Doppler capabilities. If flow is disturbed, as in stenoses or regurgitation, abnormal or turbulent patterns can be detected (Figure 7). By using the two-dimensional echocardiogram, the beam can be aligned anywhere in the heart, and intracardiac blood flow velocities across stenotic valves can be measured to calculate a transvalvular gradient. Recently, a color flow Doppler system has been introduced which interprets Doppler signals over a wide sector and displays the frequency shifts in color specific patterns. Potentially this will allow quantification of regurgitation more accurately than presently available methods.

Echocardiography is a valuable tool both for noninvasive evaluation of valvular and coronary disease. Newer applications will increase the ability of clinicians to evaluate their patients more completely, thereby improving patient management.